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SLAB ON GROUND

(Gulv pa Grunnen),

10 G. Eiesland

CORPS OF ENGINEERS, U.S. ARMY
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE

 037100

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER Draft Translation 648	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE *(and Subtitle)* SLAB ON GROUND		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Eiesland, G.		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Cold Regions Research and Engineering Laboratory Hanover, New Hampshire		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE October 1977
		13. NUMBER OF PAGES 40
14. MONITORING AGENCY NAME & ADDRESS *(if different from Controlling Office)*		15. SECURITY CLASS. *(of this report)*
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT *(of this Report)*

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

FOUNDATIONS
FLOORS
INSULATION

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

In constructing a floor slab on the ground and employing reduced foundation depth, there are three major aspects that must be taken into account, all with a basis in the Norwegian building code. (1) Foundations and floor construction must be such that they cannot be damaged by frost.--Building Code, Chapter 42:2. (2) Floors must be thermally insulated so that total heat transfer coefficient (k-value) does not exceed 0.40 kcal/m^2h^oC.--Building Code, Chapter 54:34. ~~This requirement is the same th~~roughout the country--from
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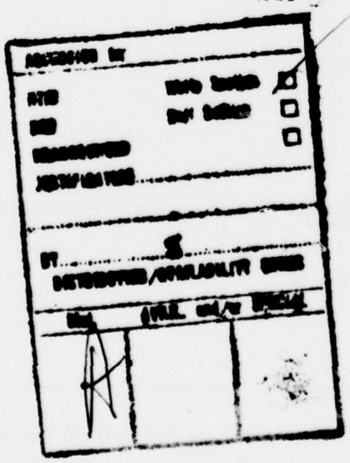

DRAFT TRANSLATION 648

ENGLISH TITLE: SLAB ON GROUND

FOREIGN TITLE: GULV PA GRUNNEN

AUTHOR: EIESLAND, G.

EDITORS: A. Greatorex and W. Tobiasson

SOURCE: Fagernes, Course in Small House Foundations, April 1974, 37p.

Translated by Rosetta Stone, Nashua, N.H. for U.S. Army Cold Regions Research and Engineering Laboratory, 1976, 40p.

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Norwegian Civil Engineers Society
NIF Education Division

SLAB ON GROUND

Course in Small House Foundations

Fagernes, 24 - 26 April 1974

Lecturer:

Civil Engineer Gunnulv Eiesland
MNIF - MRIF
Multiconsult Co.
Industrigatan 59, Oslo
Tel: 60 78 80

Translated by:

Rosetta Stone Associates, Inc.
142 Main Street
Nashua, New Hampshire
(603) 882-1760

March 8, 1976

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1. SLAB ON GROUND

1.1 Introduction

In constructing a floor slab on the ground and employing reduced foundation depth, there are three major aspects that must be taken into account, all with a basis in the Norwegian building code.

1. Foundations and floor construction must be such that they cannot be damaged by frost.
   -- Building Code, Chapter 42:2

2. Floors must be thermally insulated so that total heat transfer coefficient (k-value) does not exceed 0.40 kcal/m^2 h° C.
   -- Building Code, Chapter 54:34

   This requirement is the same throughout the country -- from mildest Stavanger to coldest Finnmark -- which seems a little unreasonable. The intention of the requirement must have been to insure an acceptable floor temperature and thus there should have been a requirement for minimum floor temperature in living areas. The reason the requirement is not stated this way must be that criteria and calculation methods were lacking for slab on ground construction.

3. Floors directly on the ground in rooms for long-term or short term occupation must be designed in such a way that moisture from the ground cannot damage the floor construction or other parts of the building.

   -- Building Code, Chapter 42:4

In designing practical floors and foundations, one often affects two or all of these three major aspects by the choice of parts of the construction.

In choosing the foundation and floor construction there are a number of other factors that must be taken into account, such as: house type, topography, ground conditions, size of project and building date.

For a given house on a specific site there are two main variables, namely:

1. Choice of sills/foundation wall.
2. Choice of floor construction.

1.2 Why Slab on Ground as a Foundation Alternative?

First and foremost, because slab on ground is often the cheapest foundation form. But, at the same time, it has been my experience that such a foundation form compels us to think of how the house

is to be placed on the site and to consider the grade conditions around the house and the drainage of surface water.

Shallow, low cost electrical connections can be used if the local building authorities will accept this type of connection.

This foundation form often makes it possible to use inexpensive fill from the building site or the vicinity as a construction material in building the foundation and floor. Examples: rock fill from blasting and compressed clay fill.

The foundation form makes good contact between house and terrain unavoidable. This means a lot for appearance but it means most for those who live in the house. The height difference between ground and floor does not have to exceed 20 cm. This means generally one step at the entrance door and one step going from the living room out into the garden.

This foundation method is also very relevant when one wishes to avoid digging out a bearing layer of soil. An example of this is thin layers of dry clay crust.

Slab on ground construction has a large area of usefulness. It is somewhat limited on sites with steep grades since at least in areas exposed to frost this would usually require that the terrain be even all around the house. This would prevent one from compensating

for a dip in the terrain near the house by increasing the height of the foundation wall, or use of supporting walls and the like. Crawl space solutions and piles/pillars combined with beams provide greater flexibility in site adaptation. The slab on ground foundation method has its greatest weaknesses when work must be done in the winter.

1.3 Design Against Frost Damage

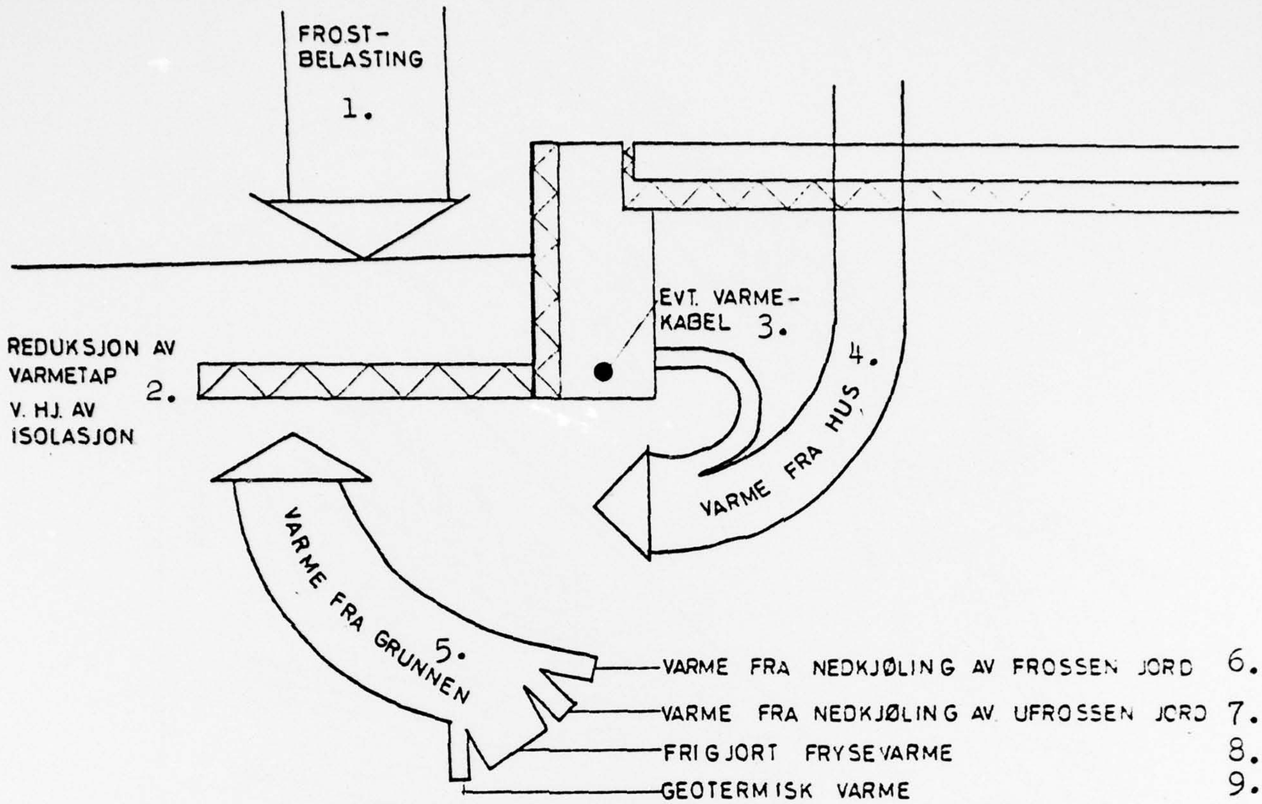
Figure 1 shows the heat and frost sources making up the thermal balance. The warm side of this balance has already been discussed in the lecture in this course delivered by Civil Engineer Erik Algaard.

For the frost load making up the cold side of the balance, frost quantity is usually used.

The frost quantity is: the sum of the product of cold degrees • hours of the entire frost season -- without deductions for periods of mild weather. The maximum frost quantities in Norway are shown in Figure 2.

This frost quantity chart, prepared by NSB* (expansion unknown) at one time on the basis of data from the Meteorological Institute has

*Possibly Norske Statsbaner, Norwegian State Railroads.



KEY:

1. Frost load
2. Reduction of heat loss with insulation
3. Heating cable, if any
4. Heat from house
5. Heat from ground
6. Heat from cooling of frozen earth
7. Heat from cooling of unfrozen earth
8. Liberated heat from freezing
9. Geothermal heat

Figure 1. Heat Balance. Slab on Ground.

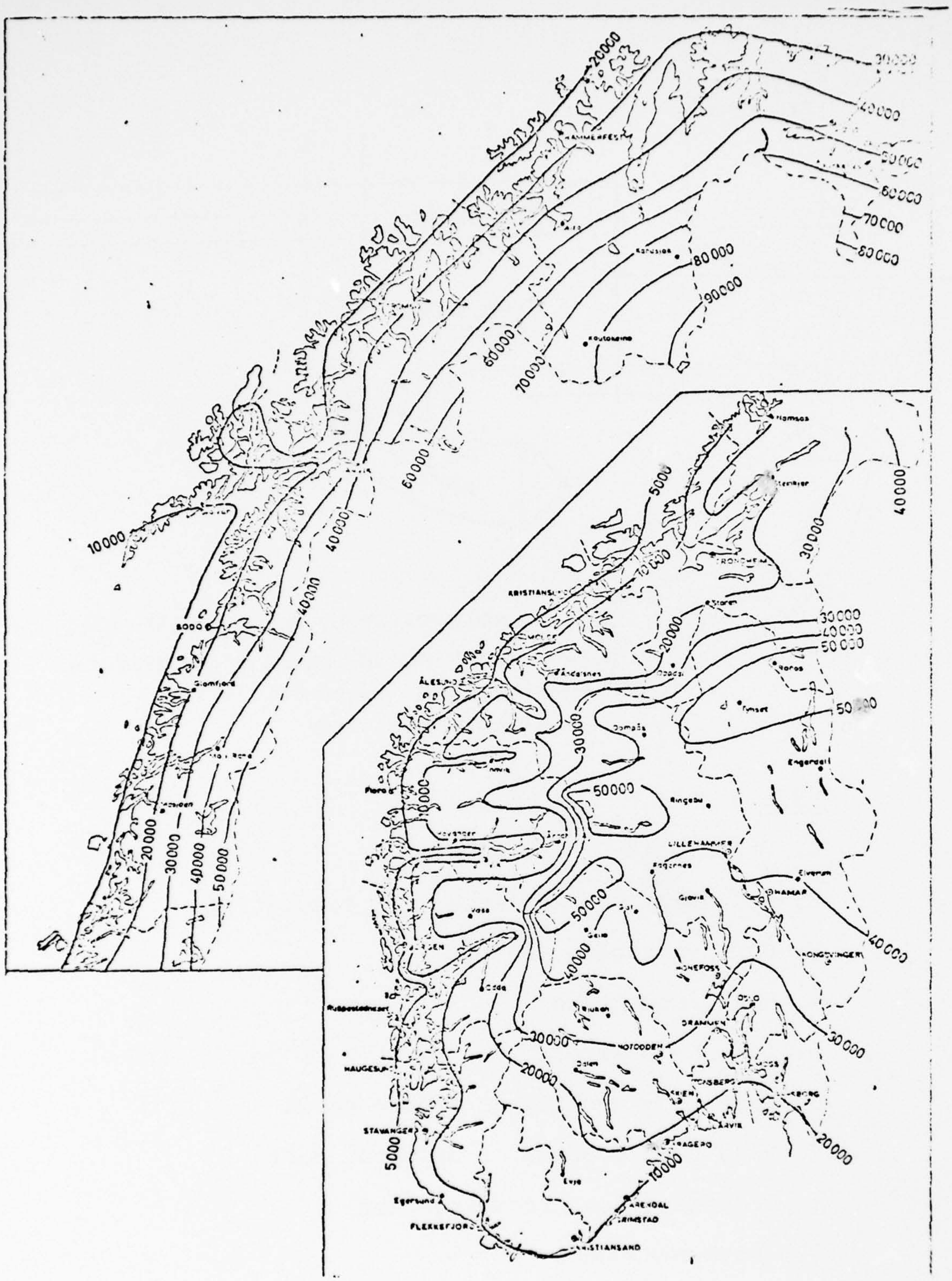


Figure 2. Maximum Frost Quantities in Norway.
F_{max} (h°C)

a good many errors and naturally does not provide information on local climate variations which can often be substantial.

The work started by the climate research division of the Frost in the Ground group at the Norwegian Technical University (Institute for Freezing Technology) will, in a few years, give us a more correct and far more detailed picture of the climatic data useful in establishing dimensions for engineering tasks.

It has been shown by Thue (1) among others that, in addition to frost quantity, the average temperature of a locality (see Figure 3) affects the frostproof foundation depth so that for places with the same frost quantity one can use a somewhat shallower foundation depth in places with a higher average temperature, Figure 4.

The variation in foundation depth based on mean annual temperature is small for heated buildings, however. Therefore, it should normally be possible to ignore the inclusion of mean annual temperature in establishing dimensions for foundation depth. The effect of mean annual temperature has not been shown for cold buildings, but we know that it would have more importance in this type of building.

The frost load due to outdoor temperature at the ground surface, as used in calculations according to the computer programs available today for two- and three-dimensional heat flow, are stated as

Figure 3. Mean Annual Temperatures (°C).

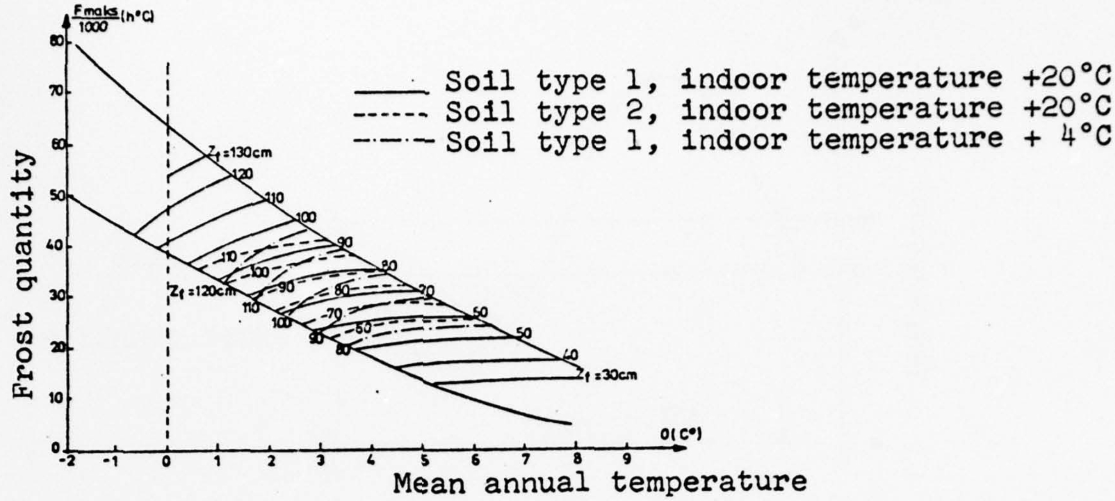


Figure 4. Types of Climate Giving the Same Frost Depth for Foundations with Reduced Depths.

follows, according to Lars Erik Jansson (2):

$$\Theta_u = \Theta_{um} + \Theta_e \cos \omega t \quad (\frac{2\pi}{\omega} = 1 \text{ year})$$

where:

Θ_u = outdoor temperature at timepoint t

Θ_{um} = normal mean annual temperature (30 year average)

Θ_e = amplitude value determined so that the area between the cosine curve and the 0°C axis is equal to the greatest observed frost quantity in the last 50 years.

This can be shown in Figure 5.

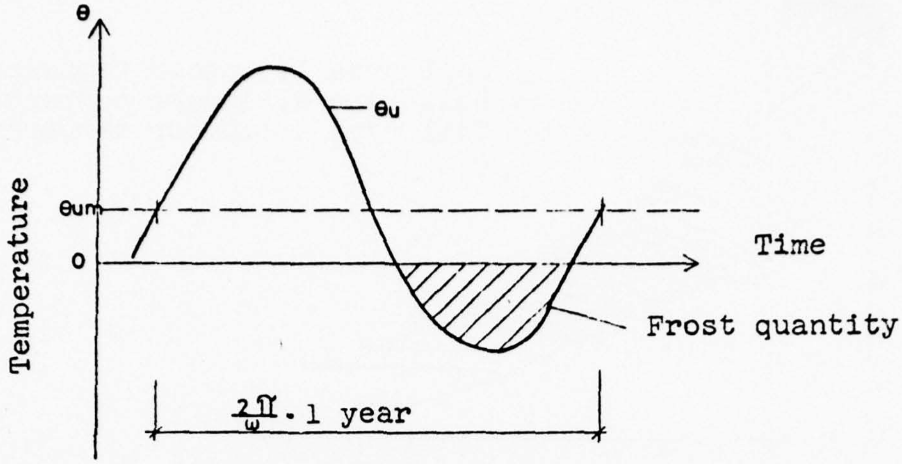


Figure 5.

Professor Adamson has compared this cosine function with the effect of observed 5-day mean temperatures in Sweden and found that this is a good expression of the actual maximum frost load.

Thue (3) also discussed this cosine function and obtained results that confirm Adamson's conclusions.

1.4 Climate Zones.

This lecture will later include design examples based on knowing the frost load.

However, when the user does not know much about this (do it yourself projects, etc.), it is sometimes desirable to work out typical solutions acceptable for the parts of the country which have approximately similar climatic conditions.

In Chapter 54:2 of the Building Code, the country is divided into four temperature zones, Figure 6. This division into zones is intended as a guide for designing heat insulation in walls, roofs, etc. in contact with the open air. A comparison with the frost quantity map, which better expresses the frost load one is working with, shows that the zone division of the building code is unsuitable for establishing thermal dimensions for floors built on the ground.

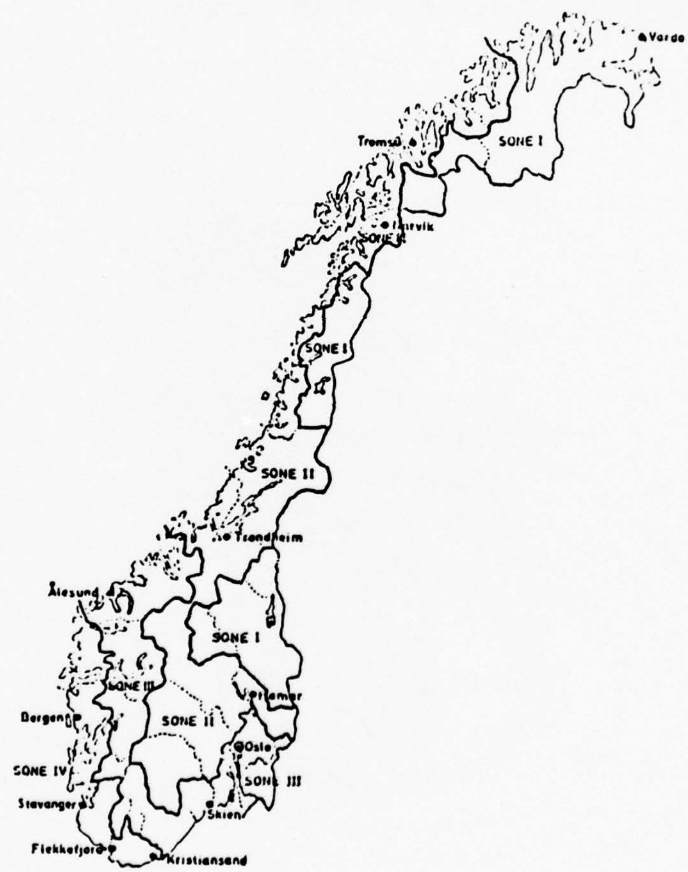


Figure 6. Temperature Zones.

As part of the climate work being done in Frost in the Ground, a climate zone division has been suggested as shown in Figure 7, with a total of 14 different zones. For building purposes, where the frost quantity is the relevant design factor, the number of climate zones could be sharply reduced.

It might be desirable to entirely free the typical solutions from the division into climate zones and instead relate them to frost quantity. This is because the climate varies a great deal over quite short geographical distances in Norway.

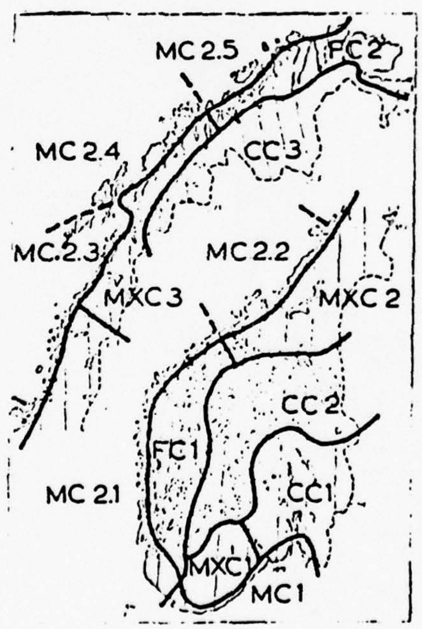


Figure 7. Climate Zones for Establishing Thermal Insulation of Walls. (Committee on Frost in the Ground)

2. DESIGN FOR ACCEPTABLE FLOOR TEMPERATURE

2.1 Building Code Requirements.

The building code states the requirement for the k-value from indoor to outdoor air as $k = 0.46\ W/m^2\ K$. $\left(= 0.04\ \frac{kcal}{m^2 h^\circ C} \right)$

This applies to a strip 6.0 m wide. Elsewhere the requirement is that the joint between floor and foundation wall be designed in such a way that no harmful cold bridge is formed.

As mentioned in the introduction, there ought to be a minimum requirement for the surface temperature of the floor for rooms that will be occupied for shorter or longer periods of time and where the room temperature is kept at, for example, 20°C.

2.2 Which Should be Applied to the Floor?

Professor Bo Adamson (4) has suggested that floor temperatures should not go below 16°C. This requirement applies up to a 30 cm distance from the outside wall and covers what might be called the dwelling area of the room. It is intended to include this requirement in the Swedish Building Code which is now under revision. This requirement is based, among other things, on experience as to what people regard as an acceptable floor temperature when they are sitting in a room with their feet on the floor.

Adamson has made calculations showing that if this requirement is applied to an outside wall, the floor temperature at a projecting corner will be about 1.5°C lower. With this requirement, there would be no danger of condensation anywhere at the joint between floor and walls, if the construction is designed with cold bridge barriers and sensible foundation support details.

2.3 Floor Covering Requirements.

Schule (5) has carried out experiments and discussed theoretically the temperature and heat flow conditions on the floor. Civil Engineer Torgersen of the Norwegian Building Institute has made a summary of this which is given below.

> The feeling of comfortable warmth on the feet and legs is closely tied to the amount of heat conducted away from the feet. The heat can be conducted away through the soles when these are in contact with the floor surface or conducted from the lower part of the legs to the surrounding air. Which of these forms of heat loss will determine the feeling of comfortable warmth depends primarily on what kind of foot covering one is wearing. With bare feet, the heat transfer from the sole of the foot to the floor is the determining factor and the effect of heat loss to the surrounding air will not be a significant factor. With footwear, which often provides a significant thermal resistance between

foot sole and floor, draft conditions and low air temperatures near the floor as well as low floor temperatures with a long period of contact with the floor will be dominant for the feeling of comfortable warmth.

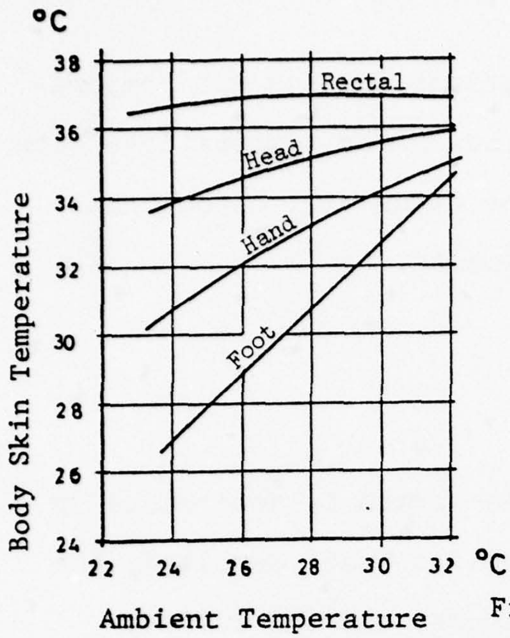
2.4 Conclusions.

For bare feet the feeling of comfortable warmth is determined by floor materials (heat conductivity, specific heat, density), the thickness of each layer, sequence of layers, and the surface temperature of the floor.

This means that the floor covering in rooms where small children play or where people walk barefoot should have a low heat conductivity. But if the floor temperature is too low (below 16°C, for example) the floor will feel cold to the skin very quickly anyway.

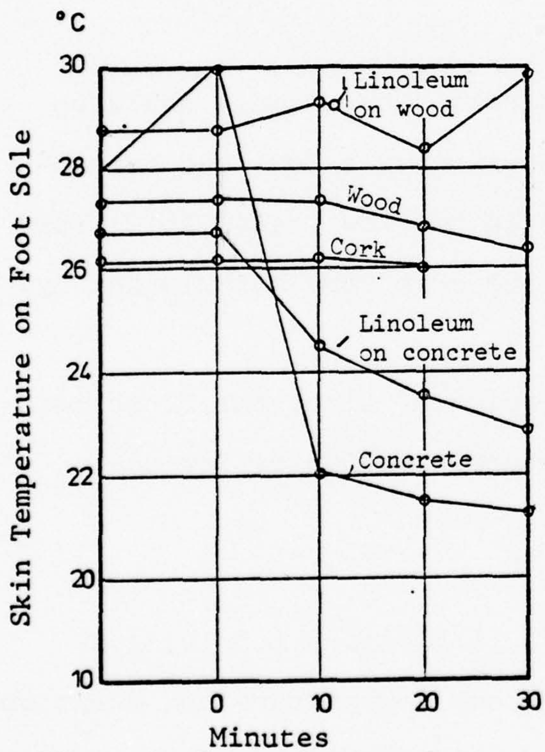
If one remains in a room for a long period of time, the floor temperature will, in all cases, be the determining factor for the feeling of comfortable warmth.

For shod feet the floor material plays little part in giving a feeling of comfortable warmth. Here floor temperature and duration of the stay along with air temperature near the floor are determining. Figures 8, 9, 10 and 11 illustrate the nature of the problem.



Skin temperature is largely dependent on the surrounding temperature. This is especially true of arms and legs.

Figure 8.

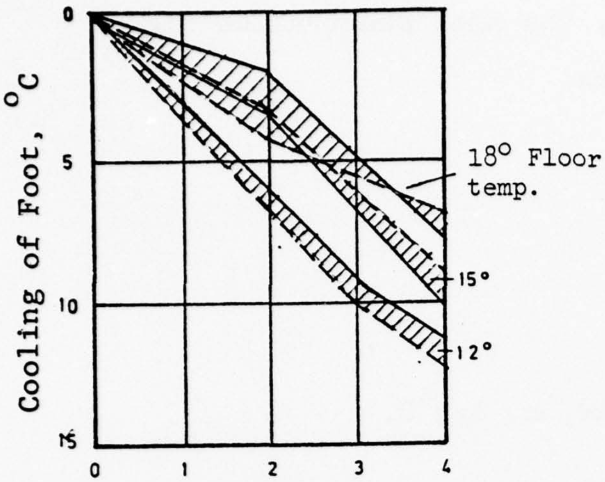


Standing on a concrete floor, the sole of the foot will experience a sharp temperature reduction, while contact with cork, wood, or linoleum on wood produces little reduction in temperature.

Time Elapsed after placing foot on floor.

Bare Foot   Room temp. 18.3°C
             Floor temp. 18.3°C

Figure 9



__________ = Wood floor

\- - - - - - - - - = Cement floor

Air temperature = 20°C

Shod Feet

When floor temperatures are low, foot sole temperatures fall even when feet are shod. Floor covering plays a small part then.

Figure 10

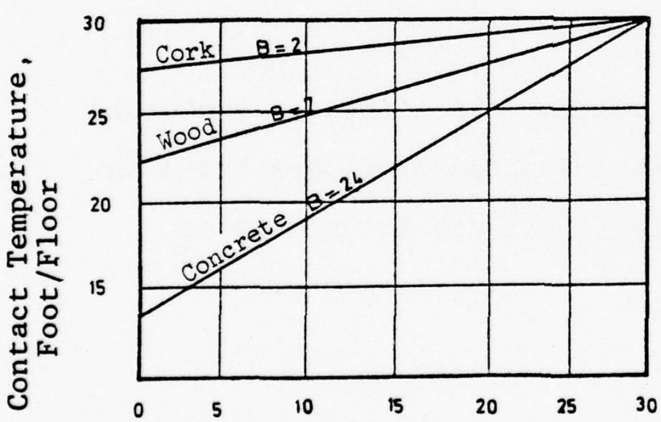


Figure 11 shows that for substances with a low heat conductivity, contact temperature depends relatively little on the surface temperature of the material. However, for substances with a high heat conductivity, contact temperature depends to a large extent on surface temperature.

Figure 11

Comfortable warmth or, more precisely, the heat penetration figure given in Figure 11 is $B = \gamma c \lambda$, where

γ = specific weight

c = specific heat

and λ = heat conductivity

In Figure 11, B is expressed in kcal/m^2, h, 1/2°C.

For floors under ordinary temperature conditions to feel comfortable when one stands on them with bare feet for 5-10 minutes, B should be < 10.

If the floor covering is thin, the number B alone does not give a correct picture of comfortable warmth.

There is a need to have floor construction classified on the basis of comfortable warmth and to set requirements for floors based on various uses. The Norwegian Building Institute is working on this now.

2.5 Design of Floor Insulation.

Today there are computer programs available for two-dimensional heat flow that are useful in calculating floor temperatures and thus the dimensions of floor insulation.

Professor Bo Adamson (4) has calculated floor temperature for a number of construction types. His recommendations are based largely on using artificial heat in the form of heating cables, radiators, etc. to achieve an acceptable floor temperature in the peripheral zones if the floor or the ceiling are not heated.

Of the Norwegian constructions that have been widely used, the Skjetten solution has heating cables while the Selvaags solution (see Figure 19) does not, but residents have complained of cold floors with the Selvaags solution. Recommendations for floor designs with respect to temperature will be made in connection with the work done on simplified foundation methods, an offshoot of the Frost in the Ground activity.

3. SLAB ON GROUND DESIGN

This section is based mainly on Jan Vincent Thue's summary of the subject from his graduate degree work at the Institute for House Building Technology, Norwegian Technical University, published in Frost in the Ground No. 13, March 1974 (6).

The work concentrates primarily on thermal problems involving foundation depth, in other words the problem of frost heaves. To help understand the diagrams that follow, the following six assumptions made by Thue are listed:

1. Two soil types: a favorable soil type, 1, and an unfavorable soil type, 2.

Soil type 1: fine texture $\rho_d = 1300$ kg/m³, W = 40%

$$\lambda_1 = 2.27 \text{ W/mK}, \lambda_2 = 1.20 \text{ W/mK}$$

$$c\rho_2 = 500 \text{ Wh/m}^3\text{K}$$

Soil type 2: coarse texture, $\rho_d = 2000$ kg/m³, W = 5%

$$\lambda_1 = 1.98 \text{ W/mK}, \lambda_2 = 2.27 \text{ W/mK}$$

$$c\rho_2 = 500 \text{ Wh/m}^3\text{K}$$

2. To further reduce the number of parameters that can be involved, Thue operates with two floor types, namely:

Alternative A: no insulation material in the floor, and

Alternative B: minimum insulation according to code requirements.

3. To make it easier to compare calculation results a "standard" thermal insulation is always used with λ = 0.046 W/mK.

4. The 0°C isotherm is considered the frost front. By frost depth at the foundation is meant calculated depth

of the intersection between the 0°C isotherm and the vertical line in the external foundation wall. This premise is somewhat conservative and will be revised in preparing dimensions for the work done by Frost in the Ground.

5. The insulation discussion is carried out for a frost load with a frost quantity of 57,000° Ch and θ_{um} = 0.5°C.

6. Indoor temperature is 17 - 20° C.

3.1 Insulation of Foundation Wall.

To prevent unnecessary heat loss from the floor, the foundation wall is usually insulated. Heat loss through the foundation wall helps to lower the floor temperature along the outside walls and energy is also lost that could be used to heat the ground at the lower edge of the foundation.

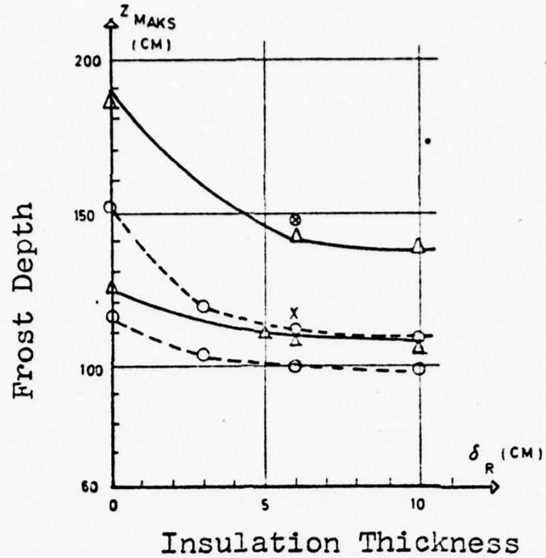
The different thermal properties of cement and soil normally cause a cement wall in damp ground to act as a "heat bridge." From a thermal point of view it is therefore an advantage to insulate the foundation wall on outside: the heat loss from the foundation wall in contact with the outdoor air is reduced and the cement conducts the heat from the floor down to the lower side of the foundation. With internal insulation the heat loss through the

floor can be kept at the same level as with external insulation but, if no additional steps are taken, one will have a relatively large heat loss from the upper part of the foundation wall which contributes to lowering the temperature at the lower edge of the foundation.

This is why more recent foundations have been developed where the foundation wall is placed on load-bearing insulation which benefits the internal insulation of the foundation wall.

The advantage of having internal foundation wall insulation is, among other things, that it gives a sturdy external surface and protects the insulation from mechanical stress.

Figure 12 shows how maximum frost depth at the foundation (Z_f) depends on foundation wall insulation in some cases. One sees that Z_f declines when δ_r (thickness of foundation wall insulation) increases. But the change is not as great when insulation thickness is increased: if δ_r is increased from 6 to 10 cm, Z_f changes by only a couple of centimeters. The variation of frost depth with δ_r depends on the ground properties and obviously this variation is considerably greater when the floor is insulated than when it is not. For a soil type with high conductivity and low heat capacity (soil type 2), foundation wall insulation has a much larger effect on frost depth than when the soil type has relatively low conductivity and high capacity (soil type 1).



o : No floor insulation
Δ : Floor insulation
x : Foundation wall insulated internally, soil type 1
⊗ : Foundation wall insulated internally, soil type 2

Figure 12. Influence of Foundation Wall Insulation on Frost Depth of Foundation. Upper Value Soil Type 2; Lower Value Soil Type 1.

Internal foundation wall insulation without floor insulation gives about the same results as an insulated floor and external foundation wall insulation. Thus the increased heat loss through the foundation wall due to moving the foundation wall insulation to the inside roughly corresponds to the reduction in heat transfer from uninsulated to insulated floors. With internal insulation and insulated floors, frost conditions become correspondingly more unfavorable.

With exterior walls of wood δ_r should not exceed about 4 cm if too eccentric a load transfer between the exterior wall and the foundation is to be avoided.

Thus insulation of foundation walls is a low cost and simple measure that obviously improves thermal conditions of the foundation: Frost depth is reduced and floor temperatures at the exterior wall become less dependent on outside temperature. Foundation wall insulation exceeding thicknesses corresponding to 5-6 cm is of little use under normal conditions.

3.2 Ground Insulation.

Exterior insulation of the ground is an alternative for reducing frost stress on foundations. Such insulation must be designed in such a way as to insure that the insulation capacity will be preserved intact in the ground -- increased moisture content in particular can destroy insulating properties. One objection that has been made to ground insulation is that in many cases this places restrictions on the use of the area just outside the house in order to prevent damage to the insulation.

With climate stress, as in the previous section, investigations have been made on the effects of various ground insulations. In the first study the floor was kept uninsulated and a 6 cm thick foundation wall insulation was used while soil types and the

thickness of ground insulation were varied. The placement of ground insulation is shown in Figure 13.

Figure 14 shows the combinations of ground insulation width and thickness giving the same frost depth (the curves have been smoothed). Lines have also been inserted here for constant quantity of insulation material. If the two curve sets are compared, one finds that a minimum quantity of ground insulation is obtained with insulation widths of 60-70 cm, regardless of which foundation depth is to be used. Such curves should be well suited to establishing dimensions of ground insulation in relation to foundation depth.

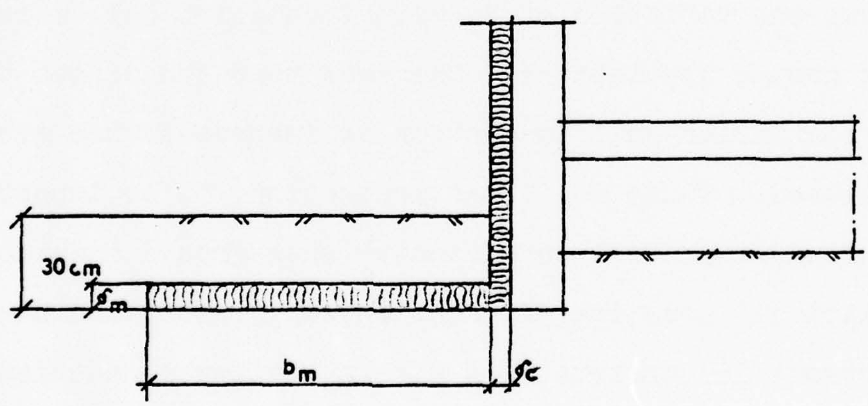


Figure 13. Location of Ground Insulation for Evaluated Cases. (With the climatic stresses used in the calculated examples, protective measures beyond the foundation wall insulation must be used if one is to prevent frost from penetrating under shallow foundations.)

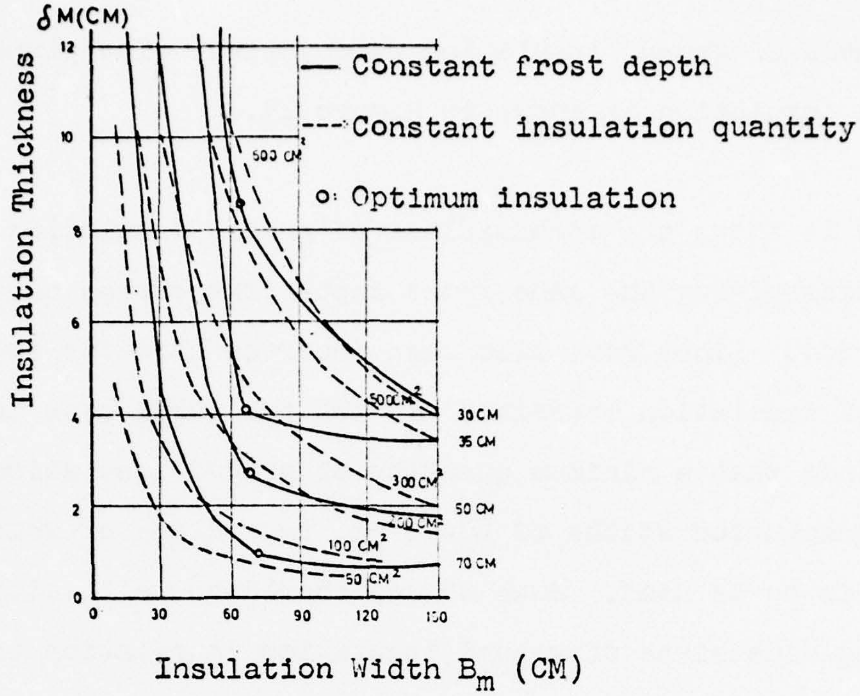


Figure 14. Frost Depth as Function of Ground Insulation, Least Favorable Soil Type.

Figure 15 shows the variation of Z_f with foundation wall insulation for different ground insulations. One sees that the effect of increasing the foundation wall insulation is increased when ground insulation is used. Thus, for frost protection, it is important to insulate the foundation wall sufficiently when ground insulation is used. Relatively speaking, foundation wall insulation has greater importance in constructions with a shallow foundation depth and a lot of ground insulation than in those with a greater foundation depth and less ground insulation. The range of variation in frost depth due to differences in soil type properties appears to decline with increased quantities of ground insulation.

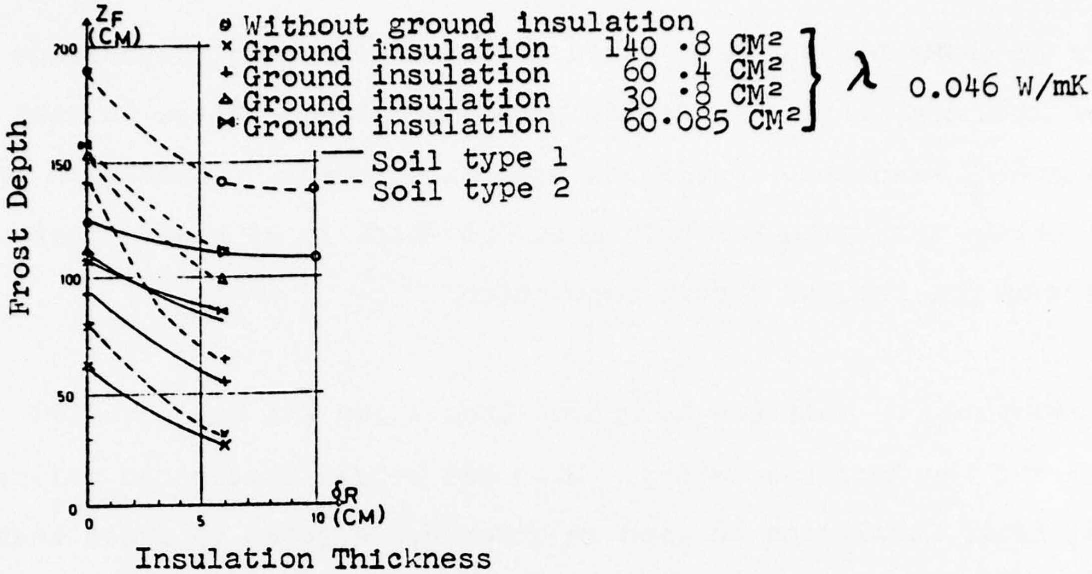


Figure 15. Effect of Foundation Wall Insulation on Frost Depth at the Foundation for Various Types of Ground Insulation. Floor Insulation, Alternative B. Climate Zone 1.

4. CHOICE OF GROUND INSULATION MATERIALS

4.1 General Remarks.

Many evaluations should be made in choosing insulation materials for ground insulation, foundation wall and floor insulation.

The main problem has been , and still is, to know how insulation materials perform thermally when placed in the ground or in different floors. The heat conductivity figure usually provided by material producers applies to use under almost dry conditions.

Figure 16 shows how the heat conductivity of expanded polystyrene varies with dampness. The figure also shows the increase in heat conductivity when damp insulation materials freeze, a condition to which little attention has been paid but which is of great importance when one chooses ground insulation.

The absorption of moisture by ground insulation has been studied by NSB and the Road Laboratory. When NSB rehabilitates old railway lines, frost insulation is used on stretches exposed to frost heaves.

NSB uses form-cast expanded polystyrene sheets with a density of at least 30 kg/m³. In addition, NSB tests materials with its own

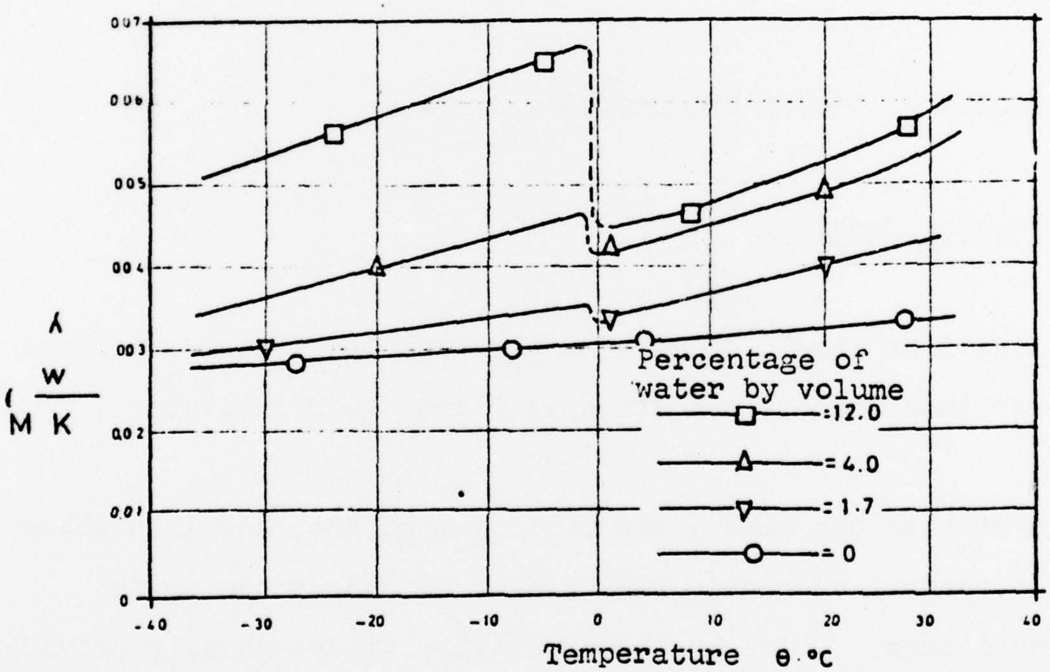


Figure 16. Heat Conductivity of Dry and Damp Polystyrene Samples.

methods (air penetration) which provides information that can be related to the moisture absorption of the material when in use.

These railroad structures have the following characteristics that are worth noting:

1. The structures in which the insulation lies are well drained.
2. The structures are open, i.e., dampness that gets into the insulation can dry out in both directions -- depending on which way the diffusion pressure is directed -- downward in the summer and upward in the winter.
3. The insulation is subjected to traffic loads. But the frequency is much less than it is on highways.

The Highway Directorate at the Road Laboratory today uses extruded polystyrene (styrofoam) or polyurethane sheets for insulating roads. The polyurethane sheets must be constructed by means of a continuous extrusion process that applies the surface layers in the same process. The Highway Directorate has had somewhat unfavorable experiences in using polyurethane sheets in top-insulated roads where the traffic load can pump moisture into the sheets. But when the insulation, as it is in new construction, is laid deeper, this problem is diminished.

One should note that in road construction:

1. Insulation sheets are laid on well-drained fill.

2. The asphalt pavement is quite impervious to diffusion and this creates a more unfavorable moisture-producing climate than, for example, that encountered for railroads and outside house foundations.

3. The traffic load and its frequency is high. This requires sheets with relatively great strength to withstand pressure.

The Highway Directorate also has test stretches with expanded polystyrene. If expanded polystyrene is used, the upper side of the sheets is usually covered with an impervious layer, for example an asphalt-coated heavy paper is often used (Sicoral) which is glued to the sheets.

Heavy mineral wool has been widely used for ground insulation in Norway. Producers state that for such use one can estimate a practical λ-value of 0.06 W/mK. The water content of up to 28% which has been demonstrated in heavy mineral wool in Finnish highway research would give a far greater λ-value than the above -- which is based on use for railroad construction. If one chooses to use mineral wool sheets, these should probably be covered with an impervious layer as the Highway Directorate does for expanded polystyrene sheets.

If one is to compare ground insulation for small house foundations with the situation in insulating ground for highways and railroad tracks, one can say that in small houses conditions lie somewhere between them:

No asphalt cover	= more favorable than for roads
Little or no traffic load	= more favorable than for either
Uncertain drainage conditions	= less favorable than for either

Based on the information it has been possible to assemble (in a relatively short time), it should, in my opinion, be possible to estimate the following average λ-values for ground insulation materials during the frost season for ground insulation used around a small house, without much traffic load and with no asphalt pavement (Table 1).

Most prices are list prices as of 13 February 1974 with an estimated addition for delivery to building sites in Oslo. The prices apply to moderate quantity purchase and do not include discounts. The heat conductivity figure is the practical value for use as ground insulation.

The right-hand column gives an "equivalent price" Pe which is the price delivered at Oslo building sites in kroner per m^3, multiplied by the heat conductivity figure (λ) measured in Watts per meter and

Table 1.

Material	Dry unit weight kg/m³	Price: delivered to Oslo site kr/m³	Heat conductivity W/m° C	Equivalent price. Pe= Price $\cdot \lambda$
Rockwool heavy sheets	150	350.00 kr	0.070	24.5
Polystyrene, form cast	30	315.00	0.050	15.75
Polystyrene styrofoam/IB	30	430.00	0.035	15.0
Polyurethane, sheets	35	≃ 600.00	0.025	≈ 15.0

and °C (= 1.16 · kcal/mh°C). This "equivalent price" gives an idea of the price per heat resistance unit, i.e., the thermal economy of a material, unmounted.

5. FOUNDATION DEPTH DIMENSIONS

Adamson (7) has calculated foundation depth based on frost load for five towns in Sweden:

Lund	F_{max}	= 13 000 h°C
Stockholm	F_{max}	= 24 000 h°C
Örebro	F_{max}	= 23 000 h°C
Härnösand	F_{max}	= 32 000 h°C
Haparanda	F_{max}	= 47 000 h°C

Adamson's choice of unfavorable soil type "Clay I" is discussed in the preceding lecture by Civil Engineer Erik Algaard.

Foundations chosen for the calculations had external base insulation if there was any.

Thue (1) has discussed foundation depth in the building code's climate zone I, assuming:

$$F_{max} = 57\ 000 \text{ h°C} \quad \text{and} \quad \theta_{um} = 0.5\text{°C}$$

which corresponds to Røros. Thue's discussions also assume external foundation wall insulation.

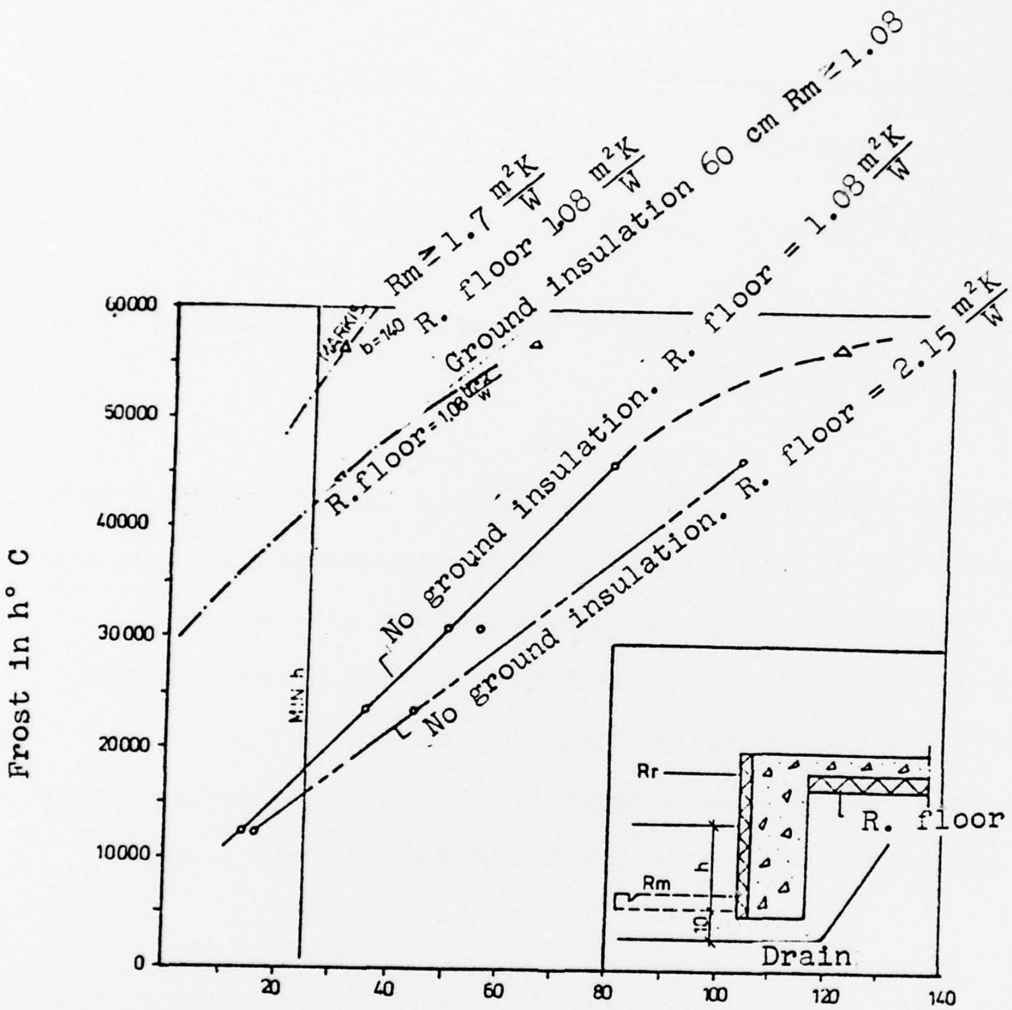
The lecturer has summarized the calculations into a design diagram, Figure 17, and this figure should provide the necessary basis for determining foundation depth for constructions with external foundation wall insulation. This should provide a basis for the choice of ground insulation/foundation depth and it should be possible to interpolate this between the curves in choosing other amounts of ground insulation or for variations in the floor insulation.

Professor Bo Adamson is preparing a manual for slab on ground construction. The book will be published in the near future.

FOUNDATION DEPTH ON THE LONG WALL

ASSUMPTIONS:

Foundation wall insulation Rr $\geq 1.08 \frac{m^2K}{W}$ externally. Base depth 30 cm. Room temperature 17-20°C. Ground conditions: clay, unfavorable.



O - According to Adamson
Δ - According to Thue

Figure 17.

With Base Height 60 cm and Foundation Depth 10 cm

Frost Quantity h°C	Ground Insulation at Corners
< 10 000	None
10 - 15 000	Rm ≥ 0.86 $\frac{m^2K}{W}$ width 60 cm. 90 cm from corner
15 - 25 000	Rm ≥ 1.50 $\frac{m^2K}{W}$ width 60 cm. 90 cm from corner
25 - 35 000	Rm ≥ 2.15 $\frac{m^2K}{W}$ width 60 cm. 150 cm from corner
35 - 45 000	Rm ≥ 2.15 $\frac{m^2K}{W}$ width 90 cm. 200 cm from corner
45 - 60 000	Rm ≥ 2.15 $\frac{m^2K}{W}$ width 120 cm. 250 cm from corner

5.1 Computer Programs.

Until more comprehensive design recommendations are available, necessary foundation depth and floor temperature can be determined with available computer programs (Thue, Megaard), which are operative at the Norwegian Building Institute.

6. WINTER PROTECTION/COLD BUILDINGS

The title of this section includes both winter protection and cold buildings since the problems involved here are quite analogous.

Slab on ground for cold buildings has been discussed by the Canadians Robinsky and Bespflug, University of Toronto (8). Their design data are reproduced in Figure 18 in somewhat revised form.

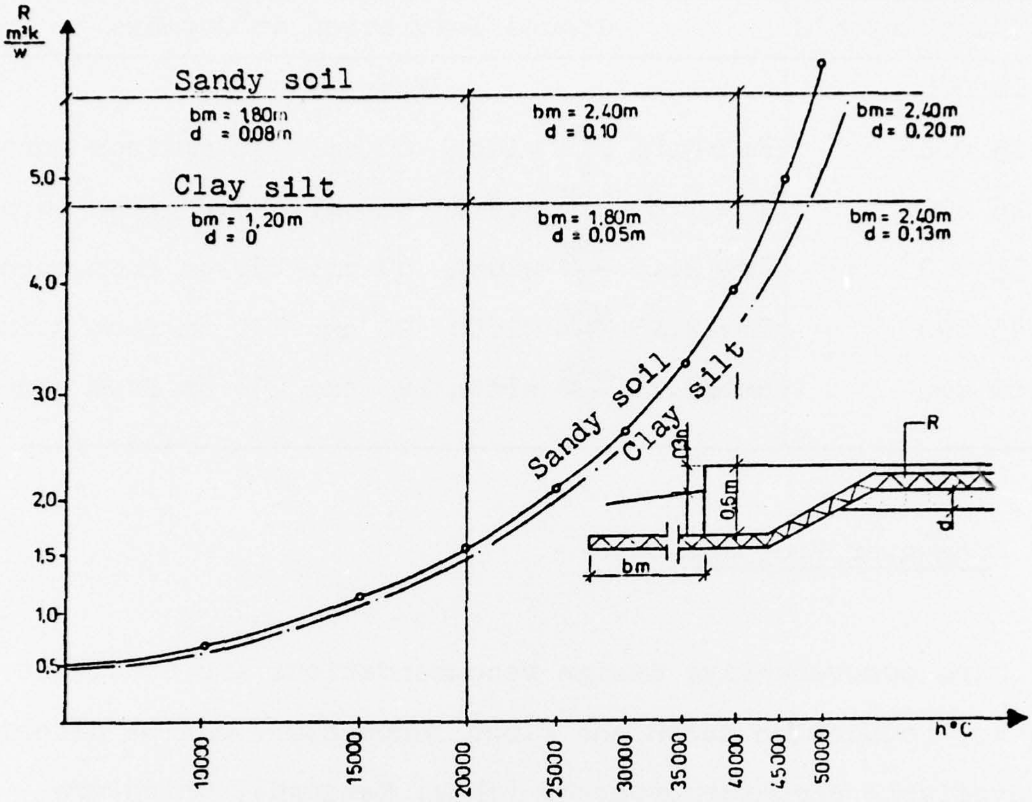


Figure 18.

Winter protection can be divided into the following tasks:

1. Coverage of slab on ground built in the summer half of the year to be left over the winter or built on some time during the winter.

2. Coverage of the ground for the building of slab on ground in the winter.

covering foundations with the expectation of building houses in the winter is expensive. At Skjetten this came up to about 15 kroner per m^2 foundation surface for the entire project -- i.e. including the foundations that had been laid and built on during the summer. One can then ask if it is not less expensive -- and better -- to put this money into permanent insulation as Selvaag Construction Company did in its foundation type (Figure 19). This foundation is supposed to tolerate a frost load of 15 000°C h without any other protection, i.e., a normal Oslo winter. This also means that there is no rush to frame the house and heating it and one can avoid heating costs until the building activities that call for heat are actually being performed.

The type of winter protection used at Skjetten is shown in Figure 20.

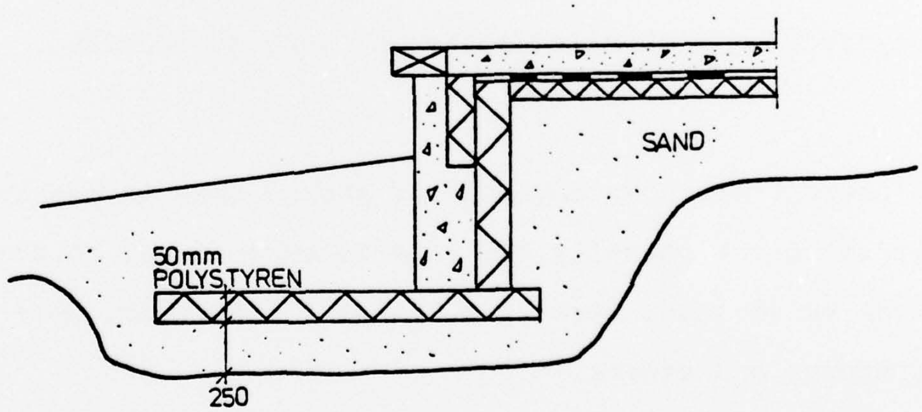
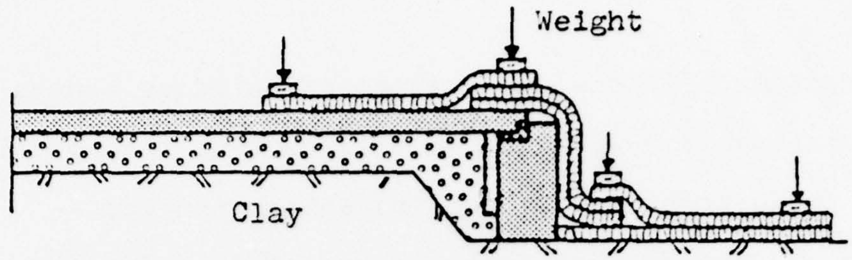


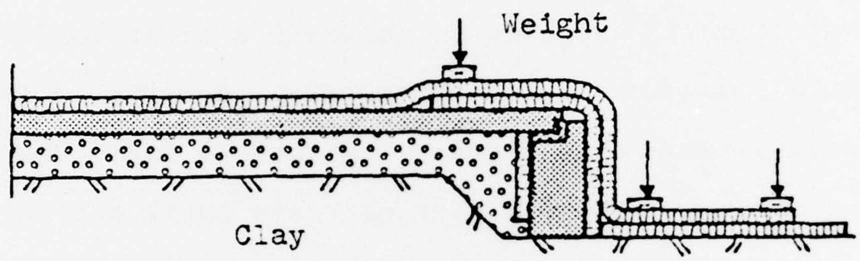
Figure 19. Foundation used by Selvaag.



Winter protection of foundations for houses to be built before 1 January.

Protective Material:

Winter mats or building mats covered with plastic



Winter protection of foundations for houses to be built after 1 January.

Protective Materials:

Winter mats or building mats covered with plastic

Figure 20. Winter Protection as Done at Skjetten.

Figure 21 shows the winter coverage of ground that is necessary depending on the frost quantity the site is exposed to, on the basis of work done by Adamson, Norwegian Building Institute, Thue of the Road Laboratory, and others.

Resistance values for frost insulation are given on the basis that the upper layer of the ground is allowed to freeze -- frozen layers

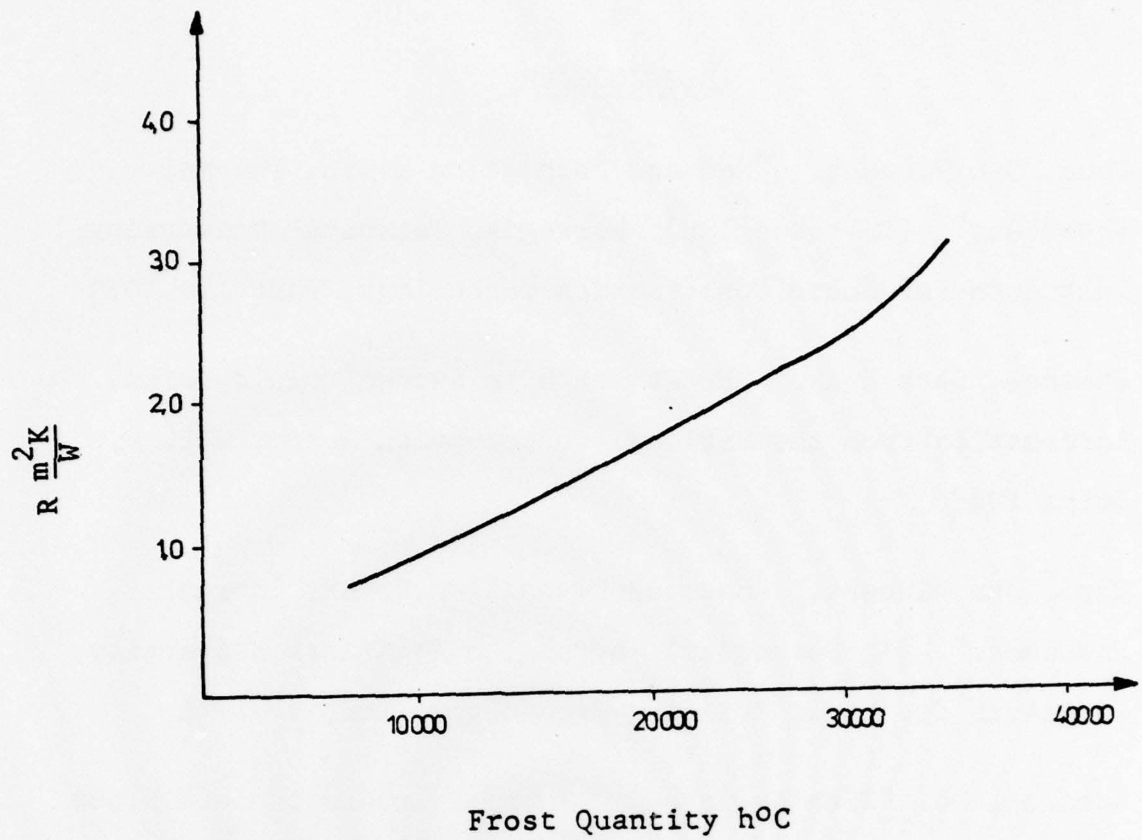


Figure 21. Necessary Insulation for Winter Protection of Ground.

less than ∿10 cm can be easily removed mechanically, for example, with a light bulldozer. Allowing a thin layer of soil to freeze reduces frost insulation requirements so much that it seems economically correct to use this as a basis.

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